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(54) Title: FLUID DEPOLARIZED ELECTROCHEMICAL BATTERY WITH AUTOMATIC VALVE

(57) Abstract

The combination of a gas depolarized electrochemical battery, i.e., a battery containing at least one cell, with one ore more tiny electrically activated, thermally responsive semiconductor microactuators, i.e., a "valve-on-a-chip", disposed over the fluid entrance inlet(s) creates an efficient gas depolarized electrochemical power supply which permits the entrance of oxygen from air to the battery only when the battery is supplying electrical power to a load. The valve-on-a-chip is singularly suited for use in a single flashlight size "C" or "D" cell. Power for the valve is preferably derived from the battery itself but could be provided by a separate source within or without the battery. The valve-on-a-chip is singularly suited for use in a single flashlight size cell or smaller. The valve acts as a safety pressure vent and can act as a safety fuse as well. When electrical power is not required from the battery, the valve excludes entry of harmful impurities and unneeded fluid reactants thereby increasing the life of the battery during storage or when the electrical device the battery is powering is idle. A resistor in parallel to the actuator valve is useful to enhance the operation of the power supply. If the battery leaks, the corrosive fluid causes the valve and/or battery to cease to operate. The combination with a recharging apparatus is also useful. The battery may be designed to regulate the flow of reactant.

FLUID DEPOLARIZED ELECTROCHEMICAL BATTERY WITH AUTOMATIC VALVE

FIELD OF THE INVENTION

This invention relates to gas depolarized electrochemical batteries including at least one cell, particularly those consuming oxygen from the air. An efficient semiconductor microactuator, i.e., a valve-on-a-chip, is placed on a sealed battery, i.e., a battery having at least one cell, so that the semiconductor microactuator is the sole means of entry of fluid depolarizer, most often air, to the battery, permitting the battery to operate when the battery is supplying electrical current to a load. The invention also encompasses micromachining a valve mechanism. The invention excludes fluid depolarizer and impurities when the battery is not supplying electrical current to an electrical load to prevent the battery from discharging and losing power capacity while not in use. The semiconductor microactuator will break down in such a way when the battery "leaks" to minimize the damage to the device the battery is operating. The semiconductor microactuator acts as a pressure relief valve. The semiconductor microactuator may also be designed to act more optimally as a safety pressure valve or as a fuse. The battery is rechargeable and this invention covers the combination with a recharger and with a control device to maximize the charge.

BACKGROUND OF THE INVENTION

Gas depolarized cells exist in many types and varieties. The most common in commercial use today are metal-air cells, especially zinc-air cells. In a zinc-air cell, the oxygen in the air, by a series of reactions, reacts with the zinc in the cell, producing electrical current. Most of the variety of gas depolarized cells to which this invention relates are

described in U. S. Patent Nos. 4,547,438, 4,529,673, 4,529,673 and literature cited in those patents.

The principal advantage of zinc-air cells is that higher energy density, i.e., watts per unit of mass, can be achieved using oxygen in the air, or other gas, as a "fluid" cathode material, instead of, the solid material found in a typical home flashlight battery. A cell of a given standard size can contain much more anode and electrolyte volume because the oxygen reactant does not need to be stored inside the battery. This is especially useful in small devices such as hearing aids and can aid in reducing the size necessary for larger cells, such as flashlight size "C" or "D" cells or even in the largest of batteries such as those used in electric cars where much power is needed but space used for storing oxygen takes away from space for other uses. Similarly, a cellular or portable phone is a good use.

Further, in a typical metal-air cell or combination of cells commonly referred to as a battery, it is the negative side of the cell, i.e., the anode, that is made of the metal, most often zinc and less often of aluminum or magnesium because of their high electromotive potential.

The positive side of a typical metal-air cell or battery, i.e., the cathode, is usually manufactured as a plastic-bonded, metal-oxide-and-carbonporous body adhered to a conductive screen or layer. The metal oxide acts as a catalyst for oxygen reduction and to give the cell start-up power as gas containing oxygen, usually air, diffuses into the cathode pores when the cell is activated.

A metal-air cell or battery also usually contains an electrolyt . The electrolyte is the material in the cell through which charged ions may

pass and where key steps of the chemical reaction producing electrical potential or voltage occur.

The metals which can be used include, for example, lead, calcium, beryllium, and lithium and alloys and mixtures of those elements. The use of the word "air" is employed for convenience to mean an oxygen source, which source could thus be other gas mixtures including oxygen.

In a single gas depolarized electrochemical cell, such as is taught in U.S. Patent No. 4,189,526 which is hereby incorporated by reference, the air enters through vent holes in the outside container of the cell through a coating of polytetrafluoroethylene often sold under the trademark "Teflon" by E.I. DuPont de Nemours & Company of Wilmington, Delaware.

When such a cell is not operating, the reactant fluid, oxygen in the air, as well as other impurities, must be excluded. Previously, no combination of a valve and battery existed where the parasitic use of power by the valve did not substantially diminish the life or the power of tha cell or consume too much space or structure.

Excluding fluids and depolarizing gas prevents the cell from degrading through several processes of corrosion, moisture change and impurity entry which may a) shorten the "shelf" or storage life of the cell when it is not in use, and b) necessitate more frequent changes of the cell in an electrically powered device. Since a common use for this type of cell is for a hearing aid, it is commercially useful not to have to change the battery so frequently.

Another common use for the cell is in a buoy at sea because the exclusion of the humid, salty sea air when the cell is not operating and reduction of the frequency in changing the cell, or cells in a battery,

save much labor and money. The control of the passage of water vapor by the valve prevents the cell from swelling or otherwise being damaged, and prevents dehydration of the cell while not operating. Also, carbon dioxide, which degrades the performance of the cell, is precluded from entering the cell when the cell is not operating.

A variety of engineering designs have previously been used in attempts to overcome these problems. Several inventions, including those disclosed in U.S. Patent Nos. 2,468,430, and 4,914,983, and in the article entitled Power Sources 4: Research and Development in Non-Mechanical Electrical Power Sources at page 342, have used a mechanism physically operated by the user where the valve or vent cover is attached to the switch turning a device "on" so that when the switch moves, the cover moves. The physical presence of the operator is required, as well as a device designed with a switch compatible with the battery system.

Another obvious and long-known approach is a solenoid or electromagnetic means to move a valve or cover as the device is turned on or off, which, consumes a substantial amount of the power of the cell or takes up substantial space.

A more primitive approach which is effective before the cell is operated is to place a sealing tab or plug on the cell (like a pull-tab on a soda can) to be removed when the cell is put in service, admitting oxygen to the assembly. The sealing tab or plug in combination with an airtight assembly at least prevents the deactivation of the zinc from external sources before use, i.e., while on the "shelf", but once activated by removing the tab, small cells must be used completely within 1 to 3 months, or the cell

will have self-discharged or dried out with no useful power remaining. If the cell is operated continuously, this "once-opened/always-opened" characteristic makes little difference, but since most electrical devices are at least occasionally turned off for a period of time, a recloseable valve is important to protect the cell from degradation during that time.

U.S. Pat. No. 4,177,327, previously mentioned, contemplates using a vent cover, in the form of a plug or a flap, in conjunction with an electrical heating element. The bimetal element in the '327 patent is referenced as 1.625 inches (4.1 cm) long. The heating element was referenced to cover 0.75 inches (1.9 cm). The embodiment in the '327 patent contemplated that the bimetal element would move to produce a clearance of 0.30 inches (0.75 cm). The moving portion of the vent cover assembly in the '327 patent is parallel or roughly parallel to the flow of air into the cell. That position requires either 1) a significant loss of dimension in the length of the cell, if the cell is a cylinder; 2) a reduction in the available space of a cylindrical cell by creation of a cavity in the side of the cell; or 3) a reduction in the height of the cell to accommodate the vent cover and heating apparatus. By comparison, a typical hearing aid battery is 1.16 cm in diameter and 0.42 cm to 0.54 cm thick. A typical size "C" flashlight battery is 2.6 cm in diameter and 5 cm high. A typical size "D" flashlight battery is 3.4 cm in diameter and 6.0 cm high. In contrast, the valve-on-a-chip is 0.4 cm x 0.4 cm x 0.1 cm in total size.

The present invention uses significantly less space and is therefore suited to a single small c ll configuration and avoids the loss in energy density

either because of lower power drain or less space consumed or both.

In addition, the present invention is intended to be used, which was not disclosed in the prior art, to act as a pressure relief valve because the cover is to the exterior of the inlet to the interior of the cell or battery so that a plug or flap is not "trapped" against the outside container of the cell or battery. Further, another objective not disclosed or intended in the prior art, is to use corrosive fluid when the battery "leaks" to clog or to distort the semiconductor microactuator and causes the cell to cease to function generally by oxygen deprivation, although it may also occur by damaging the heating element which opens the semiconductor microactuator. This more reliably causes the battery to cease to operate when it is leaking than did the devices in the prior art.

In all, the difficulty has been to produce a combination that preserves the energy density of the cell and at the same time provides a cell that can be "dropped into" a device and function automatically to preclude fluid and impurity entry while the cell and device are not operating. In addition, a pressure relief characteristic and "shutdown" of the cell on malfunction or "leakage" would be helpful, but all of these functions together have not been achieved in the prior art.

Previously, limited efforts had been made to have certain types of valves on liquid electrolyte electrochemical cells as well. U.S. Patent No. 4,039,728 discloses a valve which consumes substantial power as the means, in combination with a fuel cell, i.e., a special type of fluid depolarized electrochemical cell, to control the circulation of

liquid electrolyte in the cell. The valve is actuated based on a parameter which is a function of the circulation of the electrolyte in the cell.

This invention overcomes the power and space requirements by using the new combination of an automatic valve of different materials and size, preferably a small electronic semiconductor microactuator, a "valve-on-a-chip" similar to that of U.S. Patent No. 5,069,419 which is hereby incorporated by reference. The valve of the '419 patent and like valves, including those referenced in the '419 patent, referred to as a semiconductor actuator valve" or "valve-on-a-chip", in conjunction with a sealed gas depolarized electrochemical cell, especially a zinc-air cell. The sole means of entry of depolarizing fluid is through the valve-on-a-chip. The combination produces a new and commercially useful invention by employing recent advances in semiconductor and micromachining technology that were not previously commercially available or invented. The invention contemplates the use of at least two layers, one of metal and one of semiconductor material, juxtaposed to each other.

The preferred way that the valve and cell combination works is that when the electrical device the cell is powering is "turned on", the consequent closing of the operating circuit causes the valve to open, admitting gas, normally air, to the cell. When the circuit is opened, meaning the electrical device the cell is powering is "turned off", the valve closes, precluding entry or exit of fluids or other impurities. The valve does not close as quickly as it opens, but this time is not significant compared to the many hours of time when exposure to the air would be typically closed off, and has the additional

advantage of preventing "chatter", or unnecessary vibration, in certain applications.

There is sufficient residual oxygen or oxide compounds in the cell so that the cell will deliver sufficient power to start up and operate the valve-on-a-chip. This can be enhanced by the use of manganese dioxide or other catalytic agents in the cell. Such a cell has a higher starting power before oxygen fully penetrates the cathode pore structure. In any case, a potential of generally over one volt exists between the cell electrodes. When the circuit containing the apparatus to be operated is closed, this invention causes electrons to flow from the zinc anode(s) through the electrical circuit and the valve to the cathode(s) of the cell or cells.

This valve has the additional advantage that it is conducive to a pressure relief characteristic which continues to be usable as a vent closure after relief of the pressure.

BRIEF SUMMARY OF THE INVENTION

The primary object of this invention is to combine a new type of valve with a gas depolarized battery or cell to extend the life of the battery while preserving the energy density of the battery.

The preferred embodiment uses a micromachined electrically activated, thermally responsive semiconductor microactuator. Impurities and depolarizing gas are excluded from the battery while it is off, and when a circuit containing the battery is activated, the semiconductor microactuator opens and the battery operates. The primary characteristic of the combination that achieves these objectives is the self-contained, normally closed aspect with the means of activation internal to the valve and adjacent to the valve opening. The valve is solely activated

internally by the closing of an electrical circuit containing the valve and is not physically actuated by any means external to the valve such as an external solenoid or magnet, external mechanical or electromechanical device, physical connection with a switch or an external heating element.

The dual objectives of a valve cooperating with a battery or cell to relieve pressure, and also ceasing to function in the event of internal leakage from the interior of the battery or cell are achieved by this invention at the same time these power and size advantages are being realized.

By adding a member causing resistance in parallel with the valve to change the apparent resistance of the invention, and in particular the combined resistance of the shunt resistor and the valve, the invention can be optimized to the operational voltage or amperage of the electrical load powered by the apparatus. In a typical flashlight cell, the desired voltage is less than the standard electric potential output of a zinc-air cell, and th internal resistance of the valve mechanism and a shunt resistance member can reduce the voltage to a desired level. In keeping with the miniature size, the resistance may be a thin film resistance deposited on the semiconductor microactuator depending on th operational characteristics desired.

The invention is directed to a power supply in single cells and in batteries of cells. The invention is first directed at the combination in a single cell with an electrothermally responsive valve and a resistance means in parallel with such a valve that cooperate together to achieve certain energy density and performance characteristics. The invention is also directed toward the combination of a battery or

cell and the process of placing an electrothermally responsive valve in combination with the battery or cell. The invention is also directed at the combination of a particular type of electrothermally responsive valve, i.e, a semiconductor microactuator in a battery or cell. The invention is further directed at the method of combining the various elements of the invention.

It is an object and advantage of this invention that the valve can also be designed to release pressure at specified levels by varying the diaphragm characteristics.

By achieving such objectives, a device particularly suited for small application such as hearing aid cells, and cells the size of "D" or "C" flashlight batteries or other common sizes is realized. By not needing to change the shape of the cell because of the small valve, the cell may be "dropped-in" to existing applications without need for modification of existing electrical devices which the invention will power.

The invention also may be modified to function as a fuse at a pre-determined setting.

The invention has another objective of rechargeability and claims are directed to use with a recharger and means of optimizing recharge.

Another objective is the use of the semiconductor actuator in combination with the invention to control the circulation of electrolyte fluid.

A further objective is use of the semiconductor microactuator as a means of varying the rate of admission of depolarizing gas to the cell.

In addition, the obj ctive of better "start-up" power and op ration is achieved by mixing an additive

oxidizer with the active cathode material of the cell or cells.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1(a) is a front, top and left side perspective view of an automatic self-contained semiconductor microactuator valve.

Figure 1(b) is a front, top and left side perspective view of an automatic self-contained semiconductor microactuator valve modified with an adjusted or special resistor.

Figure 2 is a cross-sectional view of a miniature metal-air cell with a valve-on-a-chip to control air entry.

Figure 3 is a cross sectional view of a larger cylindrical metal-air cell with a valve-on-a-chip to control air entry.

Figure 4 is a cross sectional view of a battery case incorporating a valve-on-a-chip in or on the battery case to control air access to a multi-celled battery contained therein.

Figures 5(a) and (b) are front, top and left side perspective views of an automatic self-contained semiconductor microactuator valve similar to the resistors of Figures 1(a) and (b) but illustrating the contrast between the cross sections of the shunt resistor and the reduced cross section portion shown in Figure 5(b).

Figure 6 schematically illustrates the addition of a microprocessor for control purposes in series with an electrical switch.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figures 1(a), 1(b) and 2 most easily illustrate the principles of the invention. The invention is readily adaptable to the family of gas depolarized electrochemical cells.

The term battery, as used in this document, includes an array of electrochemical cells, whether connected in series or parallel, or an individual cell, unless the term cell is employed, in which case, the term battery used in the same phrase does not include an individual cell.

This invention is useful in a one cell application. This invention overcomes the power and space deficiencies associated with prior art devices by using the new combination of an automatic valve made of different materials and of much smaller size through micromachining techniques, preferably a small electronic semiconductor microactuator, a "valve-on-a-chip" similar to that of the '419 patent, in conjunction with a sealed gas depolarized electrochemical cell, especially a zinc-air cell. The sole means of entry of depolarizing fluid is through the valve-on-a-chip.

The class of valves useful in this invention is broader than that of the '419 patent because the self-contained, micromachined valve essential to this invention can include modifications of the '419 patent. The expression "electrically activated, thermally responsive valve" therefore includes the disclosure of the '419 patent and like valves that include and importantly contain a cantilever deformable element. An alternative design in this class of electrically activated, thermally responsive valves is a valve that contains juxtaposed members secured at each of their correspondent ends which members are made of materials of different thermal expansion coefficients. When one of these elements is heated, preferably the member flexing more rapidly on application of heat, the member bends and op ns a gap between the members to admit fluid. Such a design can

be achieved by modern micromachining techniques. The term electrically activated, thermally responsive valve excludes any valve or actuator which does not contain, at least partially, the deformable element since the efficiencies of the invention cannot be obtained absent some containment. Containing the deformable element achieves comparable performance to that of the '419 patent which has solely translational displacement of its deformable member as the diaphragm heating varies, which means that the valve-on-a-chip is substantially or completely non-rotational and has little or no transverse movement in the direction of flow of the depolarizing fluid, which minimizes the space usage. There can be more than two layers and the layers may be of metal or semiconductor material.

As will be apparent to those of ordinary skill in the art, while the '419 patent considers bimetallic construction of aluminum and silicon, other metals such as copper, silver, gold, zinc, etc. could be substituted for the aluminum. Other semiconductor materials such as carbon, boron, gallium arsenide or indium phosphide are contemplated as substitutions for the silicon in the invention. These materials can be used in electrically activated, thermally responsive valves as well.

The inventions disclosed in the '419 patent, the microactuators and microvalves described in the '419 patent, and their equivalent made of different materials are collectively referenced in this invention as a semiconductor microactuator or a valve-on-a-chip.

Figures 1(a) and (b) show perspective views of a self-contained micromachined, metal-semiconductor bilayer-actuated diaphragm valve described as a semiconductor microactuator similar to that of the

'419 patent and as further described in marketing materials of the assignee of said patent, I.C. Sensors, Inc. which materials are entitled Electrically-Activated, Normally-Closed Diaphragm Valves by H., Jerman, the inventor of the valve-on-a-chip. The semiconductor microactuator pictured in Figure 1 is approximately 4 mm square and 1 mm thick with the diaphragm 2.5 mm in diameter.

In Figure 1(a), a micromachined silicon valve body (36) contains a port (37), i.e., normally the outlet port to what will be the interior of the battery, a valve seat (38), and a port (39), i.e., normally the inlet port from the ambient atmosphere outside the battery, with that valve body mated to another micromachined silicon body (43) with a resistance heated diaphragm (40), and a metallized area (41) which is the resistance area for heating the diaphragm. An additional resistor, if one is added, is connected to two valve terminals (44) and (45).

A similar assembly in Figure 1(b) to that portrayed in Figure 1(a) has a shunt resistance element (42) added to the chip as shown to make the device more functional for situations where the battery current needed for the apparatus to be powered is greater than could be delivered through the semiconductor microactuator absent a shunt resistor. Alternatively, a thin film resistance element between the terminals could be added to the chip as shown, physically or by depositing metallized material on the semiconductor microactuator, to make the device more functional in its valve function-only configuration. A resistance element of optimized value and power capacity, normally between 0.05 and 1 ohms, which resistance is much less than the internal resistance of the semiconductor microactuator, could be wired in

parallel with the semiconductor microactuator as an alternative design, especially for larger battery configurations.

As shown in Figure 2, an exemplary very small gas depolarized electrochemical cell, such as for a hearing aid, is comprised of a zinc anode mixture (1) disposed adjacent to and in electrical contact with a cover (2) which is shown in Figure 2 as being round but which can be any shape and which will be negatively charged in this embodiment, which zinc anode mixture (1) is one of the electrodes of th cell. A container (11) corresponding in shape to th shape of the cover (2), which cover (2) will be positively charged in this embodiment, surrounds a gasket (3) disposed on the inside edge of th container (11), both of which surround the cover (2), so that the gasket (3) seals the cell and separates the negatively polarized cover (2) from the positively polarized container (11). Another gasket (4) is disposed on the inside corner of the container (11) to locally isolate the active cathode (7) from the inside of the container (11) so that electrical output is forced to pass through the series connected semiconductor microactuator which is mounted inside the cavity (10) of the container (11), the active cathode (7) being a porous cathode layer with a conductive metal mesh or screen in it and being one of the electrodes of the cell.

The gasket (4) is also disposed on the inside corner of the container (11) to hold adjacent to the active cathode (7), a separator (8), disposed between the zinc anode mixture (1) and the active cathode (7) to prevent the zinc anode mixture (1) from contacting the active cathode (7), and further to hold adjacent to the activ cathode (7) in successive layers

beginning adjacent to the active cathode (7), an electrolyte-proof membrane (5) made of a material such as the product polytetrafluoroethylene sold under the trademark "Teflon" by E.I. DuPont de Nemours & Company, a porous gas diffusion pad and spacer (6) with a cavity in it in which to place the semiconductor microactuator, which cavity is aligned with an air inlet (9), i.e., an aperture (9) in the container (11), so that the entry of air through the aperture (9) in the container (11) is controlled by the semiconductor microactuator, disposed on the inside surface of the container (11) with its inlet (39) over the aperture (9) in the container (11).

Electrical contacts are made internal to the cell of the semiconductor microactuator terminals (44) and (45), with or without a shunt resistor, in series to the active cathode (7) and the exterior container (11). In order to permit gas communication between the exterior of the cell and the interior, but exclude liquids and solid impurities, a gas permeable, electrolyte impermeable membrane (5) is disposed between the porous cathode layer (7) and the porous gas diffusion pad and spacer (6), which membrane (5) is made of a material such as the product polytetraflouroethylene sold under the trademark "Teflon" by E.I. DuPont de Nemours & Company. A semiconductor microactuator is disposed on the inside surface of the container (11) in the earlier mentioned cavity in the porous gas diffusion pad and spacer (6) so that the sole means of gas communication from the exterior of the battery to the interior is through the air inlet into and through the semiconductor microactuator through the gas permeable membrane (5) to the porous cathode layer (7).

Electrical connections are made from the

terminals (44) and (45) of the semiconductor microactuator to the conductive member of the cathode layer (7) and to the container (11). A resistor (42), such as a thin film resistance, is attached to the terminals (44) and (45) to be in parallel with the metallized area (41). Although not shown in the Figure, if a lower output of current from the battery is needed, a resistor in series with the semiconductor microactuator may be connected between the terminals (44) and (45) of the semiconductor microactuator (10) and the container (11).

Additional sealants, cell parts and space refinements may be also employed in such a design without departing from the spirit of the invention. When the cell is connected to an electrical load, the closing of the circuit containing the load causes current to pass through the semiconductor microactuator, causing it to open, gas such as air to be admitted, and the gas depolarized electrochemical cell to power the apparatus containing the circuit. In other words, the semiconductor microactuator functions so that when it is closed the interior of the cell is effectively sealed from the ambient, and when it is open, gas communication from the ambient to the interior of the cell case is permitted.

The previous embodiment has the semiconductor microactuator connected between the container (11) and the active cathode (7) which is one of the electrodes of the cell. In the next embodiment, the connection is made between the electrode of opposite polarity, the zinc anode mixture (1), and the container (11).

Figure 3 illustrates another preferred embodiment where the semiconductor microactuator is disposed in a larger cylindrical cell. The shape

could also be prismatic. Such a cylindrical cell is comprised of a container (12) which will be negatively charged, which container (12) is round and is shaped like a shallow pan, and has a circumferential edge upturned at a right angle and then bent again at a right angle to form a second circumferential edge parallel to and outward from the center of the container (12).

Apertures (16) are penetrated through the first upturned circumferential edge. An insulating cap (14) is placed adjacent to and centered on such container (12), which cap (14) is contained partially by such upturned circumferential edge. A solid contact member (13) is seated in such cap (14). The solid contact member (13) passes through the cell seal structure to a corrosion resistant conducting collector (25) in electrical contact with the zinc anode mixture (23). The solid contact member (13), the corrosion resistant conducting collector (25) and the zinc anode mixture (23) form one electrode of the cell.

A cavity (15) for the semiconductor microactuator as illustrated in Figures 1(a) and (b), is disposed in the corner of such container, the semiconductor microactuator being electrically connected between the solid contact member (13) of negative polarity (13) and the container (12). Adjacent to the second outer circumferential edge of the container (12) are superposed two insulating gaskets (18) on top of and beneath such outer circumferential edge. The gasket (18) on top of the second outer circumferential edge insulates an inside structural bracing member (17) adjacent to it, which inside structural bracing member (17) holds the solid contact member (13) in a centered position. Th structural bracing member (17) has an inl t (16) in it

to admit depolarizing gas to the interior of the cell over, which inlet (16) is disposed the semiconductor microactuator between the container (12) and the inside structural bracing member (17). The semiconductor microactuator is the only means of air access to the active portion of the cell.

On the inside structural bracing member (17), in a direction away from the container (12), is a sealing member (20) which is either porous or contains vent holes (19) for air entry to the porous cathode member (24). The conducting collector (25) is cylindrical and one end is seated on and attached to the solid contact member (13). Surrounding the conducting collector (25) is a zinc anode mixture (23) contained within in a separator member (21) which is shaped like an open ended cylinder with the open end sealed to the edge of the sealing member (20). Surrounding the separator member (21) is a porous cathode mixture (24) which is electrically conductive, has appropriate catalysts such as manganese dioxide, and has binders in it.

The porous cathode mixture (24) is contained within a corrosion resistant can (26) made of corrosion resistant metal or other material with conducting properties which can is shaped like an open-ended cylinder. The open end of the can (26) has a lip bent to the center of its cylindrical shape, which lip is sealed to the gasket (18) beneath the second outer circumferential edge of the container (12) and thus encloses the contents of the cell.

A positive contact piece (27) is superposed over the closed end of the can. The positive contact piece (27), the can (26), and the porous cathode mixture (24) are the electrode of the cell with opposite polarity to the electrode which includes the zinc

anode mixture. A decorative label (22) surrounds the outside of the can (26) except on the end where the positive contact piece (27) covers the can.

As in the previous embodiment as shown in Figure 2, when the semiconductor microactuator is closed, the active ingredients of the cell are effectively sealed from the ambient and when the semiconductor microactuator is open, gas communication from the ambient to the active portions of the cell is permitted.

Figure 4 shows a third embodiment comprised of and airtight non-polarized case (28) surrounding a set of connected cells (29) with apertures (30) on cells (29), having two electrodes in each cell (29), one of which is a positive pole connection member (32). The cells in this Figure 4 are connected in series with intercell connectors (31).

A cavity (33) for a semiconductor microactuator is disposed inside the surface of the case as over an inlet (35) in the case (28) and electrically connected and disposed between at least one negative terminal of the cells (29) and the negative terminal (34) of the battery assembly. The inlet (35) may have a semipermeable membrane, made from the product polytetrafluoroethylene sold under the "Teflon" by E.I. DuPont de Nemours & Company, placed to prevent non-gaseous material from entering the case (28).

The cells (29) may be connected in series as shown, or in parallel or some permutation thereof. As in the previous preferred embodiments when the semiconductor microactuator is in the closed position, the interior of the battery case (28) is effectively sealed from the ambient, and when the semiconductor microactuator is in the open position, gas communication from the ambient to th interior of the

battery case (28) and into the cells (29) is permitted.

In a plurality of cells (29) such as is shown in Figure 4, the cells (29) are internally linked in series, positive to negative pole with the "end" cells having the external electrodes. The group of cells (29) is sealed so that air can only enter through the vent holes (30).

There are many examples of gas or liquid depolarized electrochemical cells in the art, virtually all of which can be adapted, using the examples above, to use the semiconductor microactuator without substantially changing the size or power characteristics of the cell. The '438, '673 and '327 patents and literature cited in those patents illustrate the many types of cells to which this invention can be adapted.

By inserting a microprocessor chip which has voltage sensing and current sensing characteristics, and in response to either or both of thos characteristics can vary the power supplied to the valve-on-a-chip, particularly to the resistance means in the valve-on-a-chip, further refinements in optimizing or regulating fluid flow can be obtained.

Such a microprocessor chip is optimally placed in the cell adjacent to the valve-on-a-chip connected by leads to the valve-on-a-chip and container and the conductive member of the cathode layer, or placed inside the airtight non-polarized case near a terminal and the semiconductor microactuator and can be connected as shown in Figure 6.

Figure 6 illustrates a load (51) connected in series with a switch (52), control mechanism (48) and a battery (49). The control (48) has voltage sensing and current sensing characteristics and can be a

microprocessor chip which responds to voltage and current characteristics. In response to those characteristics, the control mechanism can vary the power supplied to the valve-on-a-chip, particularly to the resistor in the valve-on-a-chip. By so doing, refinements in optimizing or regulating fluid flow through the actuator, i.e., in this case using the valve-on-a-chip, can be used to alter the fluid flow into the battery (49) or alternatively, to another battery. If the batteries are connected inside an airtight nonpolarized case to a terminal on the exterior of the airtight nonpolarized case, the actuator may actually be situated on the case and controlled by a mechanism in series or partial parallel with the battery group inside the case. The control and actuator mechanism can be used to optimize the load level in between subarrays of one cell or multiple cells in a battery as well as optimize recharging and discharge.

If it is desired to have the semiconductor microactuator function as a fuse then the current carrying capacity of the resistors or the shunt circuit must be designed to fail at the desired electrical current level. The material chosen for the shunt or resistors will be from among possible metals or semiconductor materials such as mentioned above to yield the optimum balance of operating resistance considered against the desired failure upon overheating caused by the undesired or higher current level. The valve body or the shunt could also be insulated to increase the heating effect so that less current was required to cause failure. Since the resistors driving the bilayer deformation are higher in value, it is anticipated that in most cas s the shunt circuit will be the fuse element intend d to

fail.

The requirement then would be to make at least a short section of the shunt of the appropriate cross section to "blow" at the desired current level. As shown in Figure 5(b), in contrast to 5(a) which is identical to Figure 1(a), the shunt resistor (42) can have a reduced cross section portion (47) to achieve the fuse characteristic.

The semiconductor actuator shown in Figure 1 will function as a pressure relief device when pressure is placed on the outlet (37) side against th diaphragm.

To design the semiconductor microactuator to function as a vent at a predetermined pressure it is necessary to make the semiconductor microactuator so that the desired vent pressure equals the sum of the pressure required to overcome the partial pressure of the depolarizing gas (e.g. oxygen of the air) plus the built-in closure force in the semiconductor microactuator diaphragm on the area of the valve seat. According to the description of the valve-on-a-chip provided by I.C. Sensors, Inc., previously mentioned, the displacement in the valve-on-a-chip is fully proportional to the force applied without hysteresis.

For a valve-on-a-chip with a 5 micron aluminum thickness of the diaphragm and an 8 micron silicon layer, and a valve seat diameter of 400 microns, the most likely opening pressure is that required to overcome the 3 psi partial pressure of oxygen in the air if the valve-on-a-chip is employed on a metal-air battery. At a sacrifice in power required to open it, the valve-on-a-chip can be designed to require greater pressure to open. The above reference from I.C. Sensors, Inc. implies that for the same valve-on-a-chip the spring constant is approximately 160 dynes

per micron.

Referring to Figure 1(a) and 1(b), either or both the valve boss (46) and the valve seat (38) can be made so interference of these parts and deformation of the diaphragm (40) occurs when the valve-on-a-chip is assembled. Then more pressure, i.e., 160 dynes per micron of deformation during assembly, will be required to open the valve-on-a-chip to relieve the built-in pressure of the valve body. The deflection of this particular valve on a chip for a 50°C temperature rise is 27.3 microns. If one assumes that 20 microns is the maximum deformation which will still permit satisfactory operation of the valve-on-a-chip, then the maximum bent pressure before release must overcome the 3200 dynes force, i.e., to achieve unloading of the diaphragm (40), and the effect of the partial pressure of the depolarizing gas, i.e., approximately 3 psi for oxygen in air. Since the area of the valve opening is only 0.0016 cm^2, the pressure in the cell must be about 3200 dynes/0.0016 cm^2 or 2,000,000 dynes/cm^2 (29 psi). Thus, the total vent opening pressure would be 32 psi.

Any value between 3 and 32 psi could be achieved by making either or both the valve boss (46) or the valve seat (38) with more or less height for interference on assembly. Since cells of this type usually are designed with a low vent pressure for safety reasons, this range covers most designs typically required.

If relief at a different or more specific pressure is desired, the use of an additional layer, or circular web of material on the deformable element in the semiconductor microactuator or changing the thickness of the deformable element will accomplish the fine tuning of the pressure relief characteristic.

Necessarily, the change in the construction of the moving or flexing element to accomplish the pressure relief characteristic may necessitate slight relocation or change to the placement of the heating element so that upon electrothermal actuation, the necessary fluid flow of depolarizing agent to the battery is maintained.

It is also a useful advantage that if the cell is subjected to a large current overload, the valve function will be destroyed breaking the electrical circuit if the valve on a chip is in series with the power device, or precluding further admission of oxygen, eventually eliminating the power capacity of the cell or cells. Further, leakage from malfunction of the cell or battery of cells will damage the opening function of the valve-on-a-chip, minimizing damage to the apparatus powered by the cell or battery of cells. Under such circumstances, the semiconductor microactuator would act as a safety device.

The valve-on-a-chip can be very small (4 mm x 4 mm x 1 mm) and thus uses very little space and can be literally "tucked" into the cell without having to alter the exterior of the cell so radically as to require redesign of the devices that the fluid depolarized cells typically operate. The preferred embodiment of the invention uses a valve that has solely translational displacement of its deformable member as the diaphragm heating varies, which means that the valve-on-a-chip is substantially or completely irrotational and has little or no transverse movement in the direction of flow of the depolarizing fluid, which minimizes the space usage.

The semiconductor microactuator is a miniature valve literally contained in a device the size of an integrated circuit "chip". When power is supplied to

the semiconductor microactuator, the semiconductor microactuator opens and allows fluid to pass while consuming little power of the cell and with minimal movement. The valve-on-a-chip is available for a variety of operating conditions, namely different flows and different power applications. The prior art discloses adding a resistor in parallel to the semiconductor actuator valve which gives the valve even broader use and more flexibility in this invention.

The dimensions of the valve-on-a-chip are approximately 4 mm x 4 mm x 1 mm. The thinnest portion of the valve-on-a-chip is perpendicular to the direction of air flow into the cell. This enables the valve-on-a-chip to be smallest in the most critical dimension to reduce space consumption in the cell and to be mounted on the exterior or interior surface of the cell container almost as if a thick paint chip is placed flat on the cell surface.

The principal applications are expected to be for small metal/metal oxide-oxygen depolarized cells but other uses can be readily envisioned and are presented in this invention. For instance, the degree of opening of the semiconductor microactuator could be controlled by a small computer, microprocessor or other means and then the semiconductor microactuator used as a regulator of reactant air, cooling air, electrolyte circulation or other fluid flows.

In an air/zinc system, each cell delivers about 1.4 volts, in series, two cells deliver 2.8 volts etc. Because this may be above the preferred ambient operating voltage of the device being powered, a shunt resistor and the internal resistance of the semiconductor microactuator may be designed to slightly reduce the ambient operating voltage

delivered by the cell. If a multiplicity of cells is connected in parallel internally and the valve-on-a-chip is connected in series with a parallel cell combination, the cells will deliver the same voltage, but more amperage or current. If the current is above the rated capacity of the semiconductor microactuator, the semiconductor microactuator must be protected.

One way to do this is by mounting the semiconductor microactuator on the surface of the cell inside a battery of cells, connecting the semiconductor microactuator so that it is in series with a single cell added for the purpose or by inserting a low resistance shunt circuit by or on the chip to divide the current flow between the semiconductor microactuator and the shunt resistor improving the overall function of the invention.

Another way to accomplish this in an array of cells in a battery, with or without a shunt resistor, is to connect the semiconductor microactuator by one of its terminals to the electrode of a single cell as before, but the other semiconductor microactuator terminal would be connected to the parallel combination of the cells. The semiconductor microactuator would still be disposed to admit air to all of the cells on the external casing of the group of cells. More than one semiconductor microactuator can be disposed and connected for each cell, or subgroup of cells in a battery depending on the use and power being delivered.

The forms of the invention shown and described in this disclosure represent illustrative preferred embodiments thereof. The invention is defined in the claimed subject matter which follows and various modifications thereof which become obvious in light of reading the description are incorporated therein.

What is claimed is:

1. A gas depolarized electrochemical power supply comprising:

at least one gas depolarized electrochemical cell having at least two electrodes, at least one of said at least two electrodes being an active cathode, and a container which includes at least one aperture to allow depolarizing gas to enter the interior of said cell through said at least one aperture;

at least one electrically activated, thermally responsive valve having two terminals and shunt resistance means for deforming on application of power to said resistance means located between said terminals wherein said at least one valve is disposed on said cell to control fluid flow through said at least one aperture;

said at least one valve being disposed to seal said cell so that fluids may enter into said cell only through said at least one valve and so that such sealing of said cell precludes fluids from entering said cell when said cell is not operating;

said at least one valve being connected between one of said electrodes and said container;

said at least one valve being actuated when an electrical circuit including said cell is closed, which actuation permits entry of depolarizing gas to said cell;

said disposition said at least one valve and said cell cooperating to deteriorate upon leakage of corrosive fluid from said cell so as to minimize damage from such leakage to an electrical device powered by said cell by causing said cell to cease to operate;

said cell and said at least one valve cooperating so that excess pressure in said cell may exit through at least one of said at least one valve; and

said at least one valve consuming sufficiently small space and power when in operation so that said cell and said at least one valve operating cooperatively consume less than 20% of the output energy density of a gas depolarized electrochemical cell of a "D" size under a load of 500mA when tested with a resistance means of less than 0.4 ohms in parallel with said at least one valve.

2. The gas depolarized electrochemical power supply as in claim 1, wherein said at least one valve has means for opening mechanically or electromechanically at a predetermined pressure.

3. The gas depolarized electrochemical power supply as in claim 1, further comprising recharging means for connection to said power supply.

4. The gas depolarized electrochemical power supply as in claim 3, further comprising measurement means and control means responsive to the result of said measurement means for preventing overcharging of said cell.

5. The gas depolarized electrochemical power supply as in claim 4 wherein said shunt resistance means is a thin film resistance.

6. The gas depolarized electrochemical power supply as in claim 5, further comprising means for insulating a heating element in said at least one valve from a body of said at least one valve so that said heating element fails in the event of overcurrent through said at least one valv .

7. The gas depolarized electrochemical power

supply as in claim 6, wherein said at least one valve is a semiconductor microactuator valve or a valve-on-a-chip.

8. In a gas depolarized electrochemical cell having at least two electrodes wherein at least one of said at least two electrodes is an active cathode, a container with at least one aperture in said container to allow depolarizing gas to enter the interior of said cell, and a fluid regulation means for cooperating with said cell comprising:

at least one electrically activated, thermally responsive valve having two terminals wherein said at least one valve contains a member which deforms on application of power to a resistance means disposed on said deformable member;

shunt resistance means connected between said terminals;

means for disposing said at least one valve to control fluid flow through said at least one aperture and to seal said cell so that fluids may enter into said cell only through said at least one valve and so that such sealing of said cell precludes fluids from entering said cell when said cell is not operating;

said at least one valve being connected between one of said electrodes and said container;

said at least one valve being actuated when an electrical circuit including said cell is closed which actuation permits entry of depolarizing gas to said cell;

said disposition means of said at least one valve and said cell cooperating to deteriorate upon leakage of corrosive fluid from the interior of said cell so as to minimiz damage from such leakage to an electrical device powered by said

cell by causing said cell to cease to operate;

said cell and said at least one valve cooperating so that excess pressure in said cell may exit through at least one of said at least on valves;

said disposition means of said at least one valve consuming sufficiently small space and the power consumed by said at least one valve being sufficiently small so that said cell and said at least one valve operating cooperatively consume less than 20% of the output energy density of a gas depolarized electrochemical cell of a "D" size under a load of 500mA when tested with a resistance means of less than 0.4 ohms in parallel with said at least one valve.

9. The gas depolarized electrochemical cell as in claim 8 wherein said at least one valve has means for opening mechanically or electromechanically at a predetermined pressure.

10. The gas depolarized electrochemical cell as in claim 9, further comprising recharging means for connecting to said cell.

11. The gas depolarized electrochemical cell as in claim 10, further comprising measurement means and control means responsive to the result of such measurement means for connection to said cell to prevent overcharging said cell.

12. The gas depolarized electrochemical battery as in claim 11 wherein said shunt resistance means is a thin film resistance.

13. The gas depolarized electrochemical battery as in claim 12, further comprising means for insulating a heating element in said at least one valve from a body of said at least one valve so that said heating element fails in the event of overcurrent

through said at least one valve.

14. The gas depolarized electrochemical battery as in claim 13, wherein said at least one valve is a semiconductor microactuator valve or a valve-on-a-chip.

15. In a gas depolarized electrochemical battery having two terminals, an airtight nonpolarized case with at least one inlet in said case to allow depolarizing gas to enter the interior of said case, at least one cell with at least two electrodes wherein one of said at least two electrodes is an active cathode and wherein said at least one cell allows depolarizing gas to enter the interior of said cell while said cell is operating, and a fluid regulation means for cooperating with said battery, comprising:

at least one electrically activated, thermally responsive valve having two terminals and wherein said at least one valve contains a member which deforms on application of power to a resistance means disposed on said deformable member and said deformation having a displacement of less than or equal to 3 mm;

shunt resistance means connected between said terminals of said at least one valve;

means for disposing said at least one valve to control fluid flow through said at least one inlet and to seal said battery so that fluids may enter into said battery only through said at least one inlet and so that such sealing of said battery precludes fluids from entering said battery when said battery is not operating;

said at least one valve being connected in series to one of said terminals of said battery;

said at least on valve being actuated when an electrical circuit including said battery is

closed which actuation permits entry of depolarizing gas to said battery;

said disposition means of said at least one valve and said battery cooperating to deteriorate upon leakage of corrosive fluid from the interior of said battery so as to minimize damage from such leakage to an electrical device powered by said battery by causing said battery to cease to operate; and

said battery and said at least one valve cooperating so that excess pressure in said cell may exit through at least one of said at least one valve.

16. The gas depolarized electrochemical battery as in claim 15, wherein said at least one valve has means for opening mechanically or electromechanically at a predetermined pressure.

17. The gas depolarized electrochemical battery as in claim 16, further comprising recharging means for connecting to said cell.

18. The gas depolarized electrochemical battery as in claim 17, further comprising measurement means and control means responsive to the result of such measurement means for connecting to said battery to prevent overcharging said battery.

19. The gas depolarized electrochemical battery as in claim 18 wherein said shunt resistance means is a thin film resistance.

20. The gas depolarized electrochemical battery as in claim 19, further comprising means for insulating a heating element in said at least one valve from a body of said at least one valve so that said heating element fails in the event of overcurrent through said at least one valve.

21. The gas depolarized electrochemical battery as in claim 20, wherein said at least one valve is a

semiconductor microactuator valve or a valve-on-a-chip.

22. A gas depolarized electrochemical power supply comprising:

a gas depolarized electrochemical cell having at least two electrodes wherein one of said at least two electrodes is an active cathode, a container having at least one aperture to allow depolarizing gas to enter the interior of said cell through said at least one aperture;

at least one semiconductor microactuator wherein said at least one semiconductor microactuator has means for controlling fluid flow through said at least one aperture;

said at least one semiconductor microactuator being disposed to seal said cell so that fluids may enter into said cell only through said at least one semiconductor microactuator and so that such sealing of said cell precludes fluids from entering said cell when said cell is not operating;

said at least one semiconductor microactuator being connected between one of said at least two electrodes and said container;

shunt resistance means disposed in parallel to said semiconductor microactuator;

said at least one semiconductor microactuator being actuated when an electrical circuit including said cell is closed which actuation permits entry of depolarizing gas to said cell; and

said disposition means of said at least one semiconductor microactuator and said cell cooperating to deteriorate upon leakage of corrosive fluid from said cell so as to minimize damage from such leakage to an electrical devic

powered by said cell by causing said cell to cease to operate.

23. The gas depolarized electrochemical power supply as in claim 22, wherein said at least one semiconductor microactuator has means for opening mechanically or electromechanically at a predetermined pressure.

24. The gas depolarized electrochemical power supply as in claim 23, further comprising recharging means for connecting to said power supply.

25. The gas depolarized electrochemical power supply as in claim 24, further comprising measurement means and control means responsive to the result of such measurement means for connecting to said power supply to prevent overcharging said power supply.

26. A gas depolarized electrochemical power supply comprising:

a gas depolarized electrochemical battery having at least two electrodes, an airtight nonpolarized case with at least one inlet in said case to allow depolarizing gas to enter the interior of said case, and at least one cell wherein said cell has two electrodes and which cell allows depolarizing gas to enter the interior of the cell at least while the cell is operating;

at least one semiconductor microactuator wherein said at least one semiconductor microactuator is disposed to control fluid flow through said at least one inlet;

said at least one semiconductor microactuator disposed to seal said battery so that fluids may enter into said battery only through said at least one semiconductor microactuator and so that such sealing of said battery precludes fluids from entering said battery when said battery is not

operating;

said at least one semiconductor microactuator being connected between one of said electrodes and said container;

shunt resistance means disposed in parallel to said semiconductor microactuator;

said at least one semiconductor microactuator being actuated when an electrical circuit including said battery is closed which actuation permits entry of depolarizing gas to said battery; and

said disposition means of said at least one semiconductor microactuator and said battery cooperating to deteriorate upon leakage of corrosive fluid from said battery so as to minimize damage from such leakage to an electrical device powered by said battery by causing said battery to cease to operate.

27. The gas depolarized electrochemical power supply as in claim 26, wherein said at least one semiconductor microactuator has means for opening mechanically or electromechanically at a predetermined pressure.

28. The gas depolarized electrochemical power supply as in claim 27, further comprising recharging means for connecting to said power supply.

29. The gas depolarized electrochemical power supply as in claim 28, further comprising measurement means and control means responsive to the result of said measurement means for connecting to said power supply to prevent overcharging of said power supply.

30. The gas depolarized electrochemical power supply as in one of claims 25 or 29, wherein said shunt resistance means is a thin film resistance.

31. The gas depolarized electrochemical pow r supply as in one of claims 25 or 29, furth r

comprising means for insulating a heating element in said at least one semiconductor microactuator from a body of said at least one semiconductor microactuator so that said heating element fails in the event of overcurrent through said at least one semiconductor microactuator.

32. The gas depolarized electrochemical power supply as in one of claims 25 or 29, further comprising means for connecting a control having a microprocessor to optimize performance for a given electrical load.

33. The gas depolarized electrochemical power supply as in one of claims 7, 25 or 29, further comprising means for circulating fluid through said cell.

34. The gas depolarized electrochemical power supply as in one of claims 7, 25 or 29, further comprising means for disposing an additive oxidizer in said active cathode of said at least one cell.

35. A method of regulating fluid flow into a gas depolarized electrochemical battery having at least one cell, comprising:

disposing at least one micromachined, electrically activated, thermally responsive valve within a gas depolarized electrochemical battery; and

connecting said at least one valve electrically to said battery so that said at least one valve only admits fluid to said battery while said battery is under an electrical load.

36. The method as in claim 35, wherein said at least one valve opens mechanically or electromechanically at a predetermined pressure.

37. The method as in claim 36, further comprising connecting a recharging means to said battery.

38. The method as in claim 37, further comprising connecting measurement means and control means responsive to the result of such measurement means to prevent overcharging said battery.

39. The method as in claim 38, further comprising connecting shunt resistance means to said at least one valve.

40. The method as in claim 39 wherein said shunt resistance means is a thin film resistance.

41. The method as in claim 40, further comprising connecting control means having a microprocessor to optimize the battery performance for a given electrical load.

42. The method as in claim 41, further comprising circulating a fluid through said battery via fluid circulation means and fluid circulation control means.

43. The method as in claim 42, further comprising disposing an additive oxidizer in an active cathode of said at least one cell of said battery.

44. The method according to claim 43, further comprising disposing an insulation means to insulate a heating element in said at least one valve from a body of said at least one valve so that said heating element fails in the event of overcurrent through said at least one valve.

45. The method according to claim 44, said at least one valve being a semiconductor microactuator valve.

AMENDED CLAIMS

[received by the International Bureau on 6 October 1993 (06.10.93);
original claims 5-10 and 16-23 cancelled;
original claims 1-4, 9-15 and 24-39 amended;
new claims 40-52 added; other claims unchanged (13 pages)]

Claim 2 (Amended).. [A power supply according to] The battery as in claim 1[,] wherein said at least one valve means [is designed to open] opens mechanically or electromechanically at a [pre-determined] predetermined pressure.

Claim 3 (Amended). [A power supply according to] The battery as in claim [1,] 2 further comprising[: connecting a] recharging means for connection to said [power supply] battery for recharging said battery.

Claim 4 (Amended). [A power supply and recharging means according to] The battery as in claim 3[,] further comprising[: connecting a] measurement means and [a] control means responsive to [the result of such] said measurement means for connection to said battery for preventing [to prevent] overcharging of said cell.

Claim 9 (Amended). [In a gas depolarized electrochemical] A battery [having] comprising:

at least two terminals[, having] protruding outwardly from an airtight, non-polarized case with at least one inlet [in said case to allow] means therein for funneling depolarizing gas [to enter the interior of] into at least one gas depolarized electrochemical cell which is enclosed by said case[, and having], wherein each of said at least one cell have at least [one cell which cell has] two electrodes[, one of which] wherein at least one of said at least two electrodes is an active cathode[, and which cell allows depolarizing gas to enter the interior of said cell at least while the cell is operating, a fluid regulation apparatus cooperating with said battery comprising:];

at least one resealable, electrically activated[,] and thermally responsive valve means located inside said battery for allowing entry of depolarizing gas into said cell through said inlet means into said cell's interior only when said cell is operating to supply energy to an electrical device which said cell is connected to as a power source, said valve means being comprised of shunt resistance means between [having] two terminals [and which said at least one valve contains a member which deforms on] located on means for deforming upon application of power to [a] said shunt resistance means [disposed on said deformable member and said deformation having a displacement of less than or equal to three (3) millimeters; a shunt resistance means connected between said terminals of said at least one valve; disposing said at least one valve to control fluid flow through said at least one inlet and to seal said

battery so that fluids may enter into said battery only thr ugh said at least on inlet and so that such s aling of said battery pr cludes fluids from entering said battery when said battery is not operating;], said at least one valve being connected in series to one of said terminals of said battery; and

means for actuating said at least one valve [being actuated when] means by closing an electrical circuit [including] which includes said battery [is closed which actuation permits] to permit entry of depolarizing gas to said cell inside said battery[; said disposition of said at least one valve and said battery cooperating to deteriorate upon leakage of corrosive fluid from the interior of said battery so as to minimize damage from such leakage to an electrical device powered by the battery by causing the battery to cease to operate; and said battery and said at least one valve cooperating so that excess pressure in said battery may exit through at least one of said at least one valves].

Claim 10 (Am nd d). [A fluid r gulation apparatus cooperating with said] The battery as in claim [11,] 9 wherein said at least one valve [is designed to open] means opens mechanically or electromechanically at a predetermined pressure.

Claim 11 (Amended). [A fluid regulation apparatus cooperating with said] The battery as in claim [11,] 10 further comprising[: connecting a] recharging means for connecting to said [cell] battery to recharge said battery.

Claim 12 (Amended). [An apparatus and recharging means according to] The battery as in claim 11[,] further comprising[: connecting a] measurement means and [a] control means responsive to [the result of such] said measurement means for connection to said battery to prevent overcharging [the] of said cell.

Claim 13 (Amended). [A shunt resistance means] The battery as [recited] in [claims 1, 5, or 9,] claim 12 wherein said shunt resistance means is a thin film resistance [means].

Claim 14 (Amended). [An apparatus] The battery as [recited] in [claims 1,5, or 9,] claim 13 further comprising[: disposing an insulation] means [to insulate] for insulating a heating element [in] located inside of said at least one valve means from [a body of] said at least one [valve so that] valve's body in order for said heating element [fails in the event of] to fail if overcurrent flows through said at least one valve means.

Claim 15 (Amended). [An apparatus] The battery as [recited] in [claims 1, 5, or 9,] claim 14 wherein said at least one valve means [being] is a semiconductor microactuator valve-on-a-chip.

Claim 24 (Amended). [A resistance means] The battery as [recited] in [claims 16 or 20,] claim 4 wherein said shunt resistance means is a thin film resistance [means].

Claim 25 (Amended). [An apparatus] The battery as [recited] in [claims 16 or 20,] claim 24 furth r comprising[: disposing an insulation] means [to insulate] for insulating a heating element [in] located inside of said at least one [semiconductor microactuator] valve means from [a body of] said at least one [semiconductor microactuator] valve means' body [so that] in order for said heating element [fails in the event of] to fail if overcurrent flows through said at least one [semiconductor microactuator] valve means.

Claim 26 (Amended). [An apparatus] The battery as [recited] in [claims 1, 5, 9, 16, or 20,] claim 25 further comprising[: connecting a] control means having a microprocessor for being connected to said battery in order to optimize said battery's performance for a given electrical load.

Claim 27 (Amended). [An apparatus] The battery as [recited] in [claims 1, 5, 9, 16, or 20,] claim 26 further comprising[: a] fluid circulation means and fluid circulation control means for connection to said battery to circulate [circulating] fluid through said cell.

Claim 28 (Amended). [An apparatus] The battery as [recited] in [claims 1, 5, 9, 16, or 20,] claim 27 further comprising[: disposing] an additive oxidizer for placement in said active cathode of said at least one cell.

Claim 29 (Amended). A method of regulating fluid flow into a [gas depolarized el ctrochemical] battery having at least one gas depolarized electrochemical cell[,] comprising:

[disposing] positioning within said battery at least one resealable, micromachined, electrically activated[,] and thermally responsive valve [with a gas depolarized electrochemical battery] means for regulating flow of depolarizing gas into said battery's interior and said cell's interior through inlet means in said battery and said cell, respectively, and through said valve means only when said battery is operating to supply energy to an electrical device which said battery is connected to as a power source; and

electrically connecting said at least one valve means [electrically] to [the battery so that] an actuator means for [said at least one valve] sealing said inlet means in said battery to prevent [only admits fluid] depolarizing gas from entering [to] said battery [while] and said at least one cell when said battery is [under an electrical load] not operating to supply energy to a device to which said battery is connected as a power source.

Claim 30 (Amended). [A] The method [according to] as in claim 29[, wherein] further comprising applying a predetermined pressure to mechanically or electromechanically open said at least one valve means [is designed to open mechanically or electromechanically at a pre-determined pressure].

Claim 31 (Amended). [A] The method [according to] as in claim [29,] 30 further comprising[:] connecting a recharging means to said battery for recharging said cell.

Claim 32 (Amended). [A] The method [according to] as in claim 31[,] further comprising[:] connecting [a] measurement means and [a] control means responsive to [the result of such] said measurement means to [prevent] said battery for preventing overcharging [the battery] of said cell.

Claim 33 (Amended). [A] The method [according to] as in claim [29,] 32 further comprising[: disposing and] connecting [a] shunt resistance means [with] to said at least one valve means.

Claim 34 (Amended). [A] The method [according to] as in claim [34] 33 wherein said shunt resistance means is a thin film resistance [means].

Claim 35 (Amended). [A] The method [according to] as in claim [29,] 34 further comprising[:] connecting [a] control means having a microprocessor to [optimize the] said battery for optimizing said battery's performance [for] under a given electrical load.

Claim 36 (Amend d). [A] The method [according to] as in claim [29,] 35 further comprising[: a fluid circulation means and fluid circulation control means for] circulating fluid through said battery via fluid circulation means and fluid circulation control means.

Claim 37 (Amended). [A] The method [according to] as in claim [29,] 36 further comprising[:] disposing an additive oxidizer in [an] said active cathode of said at least one cell of said battery.

Claim 38 (Amended). [A] The method [according to] as in claim [29,] 37 further comprising[:] disposing [an insulation] means [to insulate] for insulating a heating element [in] located inside said at least one valve means from [a body of] said at least one [valve] valve means' body so that said heating element fails [in the event of] if overcurrent flows through said at least one valve.

Claim 39 (Amended). [A] The method [according to] as in claim [29,] 38 wherein said at least one valve [being] is a semiconductor microactuator valve-on-a-chip.

Claim 40. The battery as in claim 28 wherein said at least one valve means is a semiconductor microactuator valve-on-a-chip.

Claim 42. The battery as in claim 41 wherein said valve means acts as a pressure relief valve to allow excess pressure to exit said cell.

Claim 43. The battery as in claim 42 wherein said valve means is approximately 4 mm by 4 mm by 1 mm.

Claim 44. The battery as in claim 43 wherein said cell consumes less than 20% of the output energy density of a typical size-D gas depolarized electrochemical cell under a load of 500mA when tested with a resistance means of less than 0.4 ohms in parallel with said valve means.

Claim 45. The battery as in claim 15 further comprising control means having a microprocessor for connection to said battery to optimize said battery's performance under a given electrical load.

Claim 46. The battery as in claim 45 further comprising fluid circulation means and fluid circulation control means for circulating fluid through said cell.

Claim 47. The battery as in claim 46 further comprising additive oxidizer means for disposition in said active cathode of said at least one cell.

Claim 48. The battery as in claim 47 wherein said valve means and said actuation means cooperate to cause said batt ry to cease to operate upon leakage of corrosive fluid from the interior of said battery so as to minimize damage to an electrical device which said battery is powering.

Claim 49. The battery as in claim 48 wherein said valve means is a pressure relief valve to allow excess pressure to exit said battery through said at least one valves means.

Claim 50. The battery as in claim 49 wherein said deformable member has a displacement approximately less than or equal to 3 mm.

Claim 51. A battery comprising:

a single fluid depolarized electrochemical cell having at least two electrodes and a container means wherein at least one of said at least two electrodes is an active cathode and said at least two electrodes are separated from each other by a plurality of gaskets, said at least two electrodes and said container means cooperating to form an interior chamber wherein a metal-anode mixture and a porous cathode member are housed separated from contacting each other by separator means, one of said at least two electrodes having at least one air vent hole so that depolarizing fluid may enter said interior chamber to contact said porous cathode member, a resealable, electrically activated and thermally responsive valve means placed inside said cell to connect said at least one air vent hole to said interior chamber for regulating flow of depolarizing fluid into said battery in order for said valve means to cooperate with actuator means to allow depolarizing fluid to enter said interior chamber of said cell only when said cell is operating to supply energy to an electrical device which said battery is connected to as a power source.

Claim 52. A battery comprising:
a case having a valve means therein and at least two t rminals which protrude outwardly therefrom and wherein said case encloses a plurality of fluid depolarized electrochemical cells, each of said cells having at least two electrodes and a container with inlet means and enclosing an interior chamber which houses a metal-anode mixture and a porous cathode member separated from contacting each other by separator means, said inlet means in said container of each of said cells for allowing entry of depolarizing fluid into said interior chamber of said cell to contact said porous cathode member, said valve means of said case including a resealable, electrically activated and thermally responsive valve and actuator means for regulating flow of depolarizing fluid into said battery in order for said valve means cooperating with said actuator means in order to control the flow of depolarizing fluid into said battery and thus into said interior chamber of said cell only when said battery is operating to supply energy to an electrical device which said battery is connected to as a power source.

STATEMENT UNDER ARTICLE 19

Claims 1-39 are pending in the present application. The International Search Report, mailed on 20 August 1993, cites U.S Patents Nos. 4,011,366, 5,069,419 and 4,524,673 as documents considered relevant to claims 1-34 and U.S. Patent No. 4,547,438 as a document relevant to claims 35-39. All four references have been cited as documents of particular relevance such that the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

By this amendment, claims 5-10 and 16-23 have been cancelled to reduce the issues and claims 1-4, 9-15 and 24-39 have been amended to more positively recite applicant's patentably novel invention of a fluid depolarized electrochemical battery with an automatic valve. New claims 40-52 have been added to set forth applicant's invention in varying scope.

Applicants have amended independent claims 1, 9 and 29 by more positively reciting a battery having at least one gas depolarized cell with an valve and actuator that work together to allow depolarizing gas to enter the interior of the cell only when the battery is operating to supply energy to an electrical device which the battery is powering which is not taught nor suggested by the prior art.

Furthermore, amended claims 1 and 9 clearly recite the structure of the valve as including, among other things, a shunt resistor. Amended claims 1 and 9 thus set forth the patentably novel invention of a battery having an automatic valve with a shunt resistor, which battery is not taught in the prior art.

Claim 1 (Am nded). A [gas depolarized electrochemical power supply] battery comprising:

[a] at least one gas depolarized electrochemical cell having an interior and at least two electrodes wherein said interior of said cell is enclosed within a container which includes inlet means for funneling depolarizing gas into said interior of said cell and wherein one of said at least two electrodes[, one of which electrodes] is an active cathode[, and having a container having at least one aperture to allow depolarizing gas to enter the interior of said cell through said at least one aperture];

at least one resealable, electrically activated[,] and thermally responsive valve means for placement inside of said container to allow entry of depolarizing gas into said cell through said inlet means and then into said interior of said cell only when said cell is operating to supply energy to an electrical device which said cell is connected to as a power source, said valve means being comprised of shunt resistance means between [having] two terminals [and which said at least one valve contains a member on which deforms on] located on means for deforming upon application of power to [a] said shunt resistance means [between said terminals disposed on said member which said at least one valve is disposed to control fluid flow through said at least one aperture; a shunt resistance means connected between said terminals; said at least one valve being disposed to seal said cell so that fluids may enter into said cell only through said at least one valve and so that such sealing of said cell precludes fluids from entering said cell when said cell is not operating; said at least one valve being

connected between one of said electrodes and said container; said at least one valve being actuated when]; and

means for actuating said valve means by closing an electrical circuit [including] which includes said cell [is closed which actuation permits] to thus permit entry of depolarizing gas to said interior of said cell[; said disposition of said at least one valve and said cell cooperating to deteriorate upon leakage of corrosive fluid from said cell so as to minimize damage from such leakage to an electrical device powered by said cell by causing said cell to cease to operate; said cell and said at least one valve cooperating so that excess pressure in said cell may exit through at least one of said at least one valves; and said disposition of said at least one valve consuming sufficiently small space and the power consumed by said at least one valve when operated being sufficiently small that said cell and said at least one valve operating cooperatively consume less than 20% of the output energy density of a gas depolarized electrochemical cell of a "D" size under a load of 500mA when tested with a resistance means of less than .4 ohms in parallel with said at least one valve].

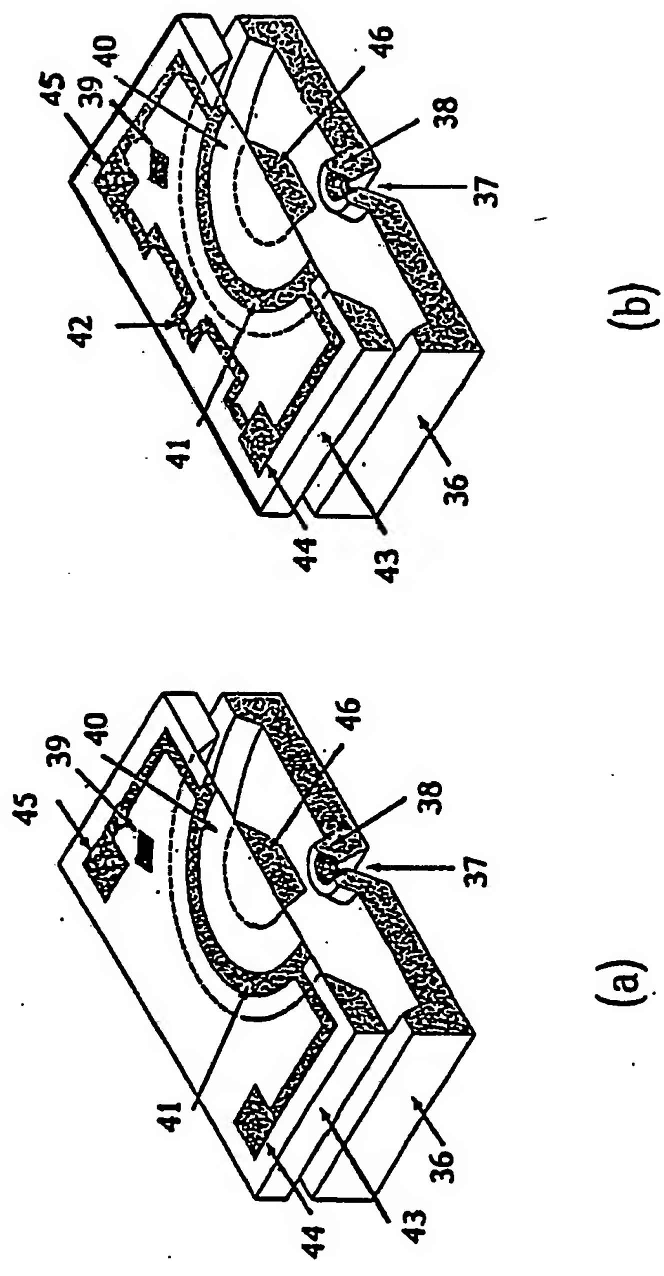

Figure 1.

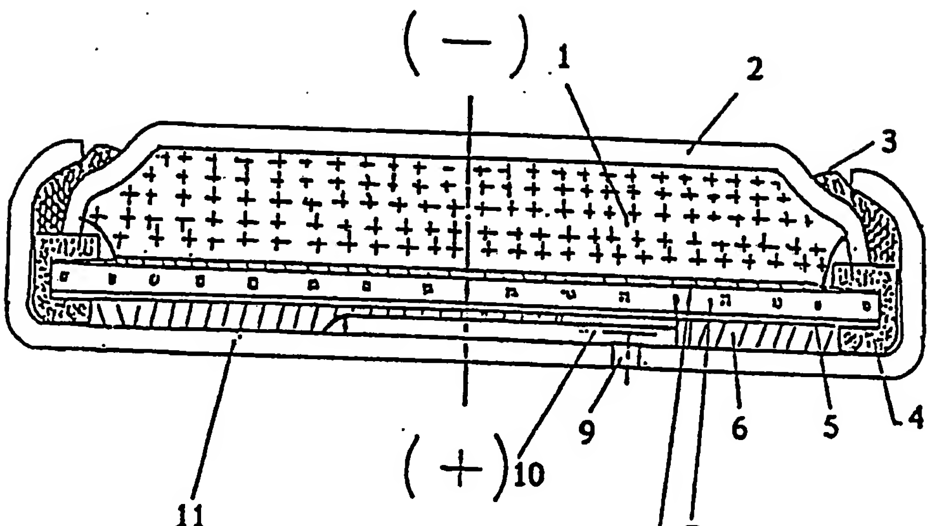

Figure 2.

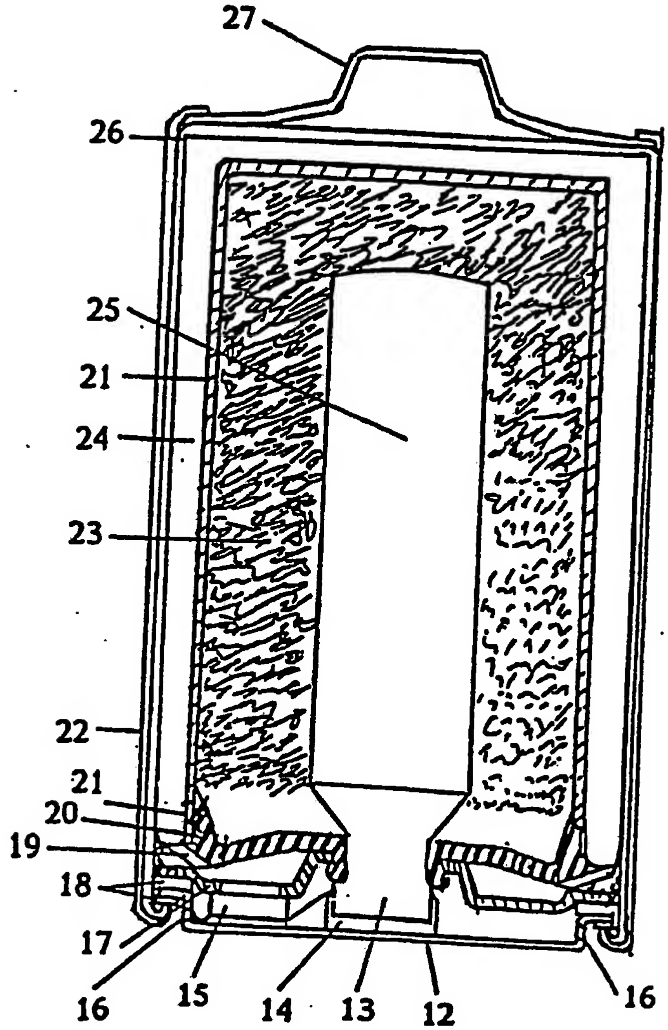

Figure 3

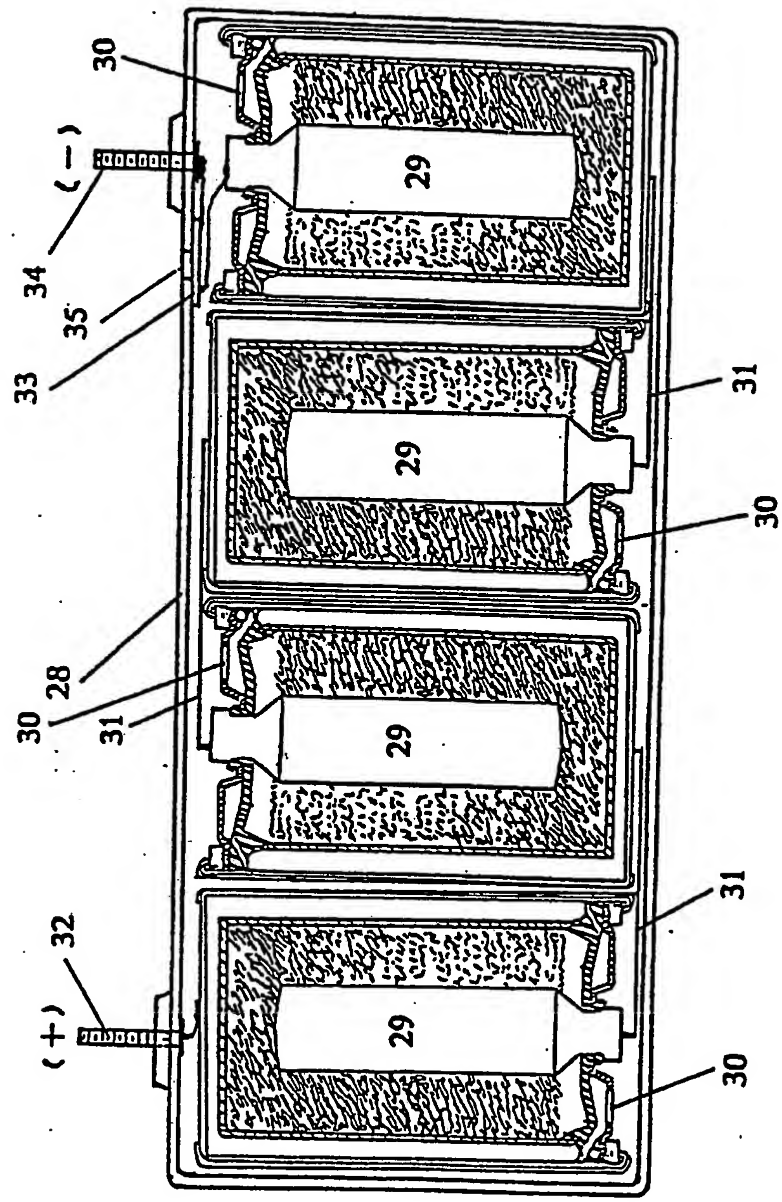

Figure 4

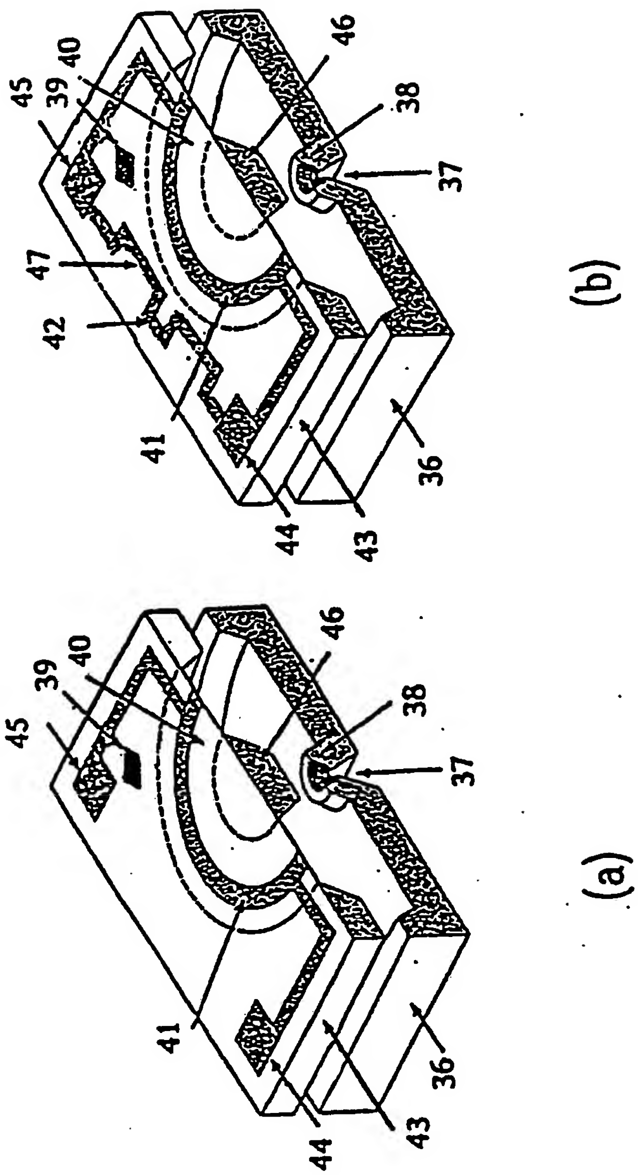

Figure 5.

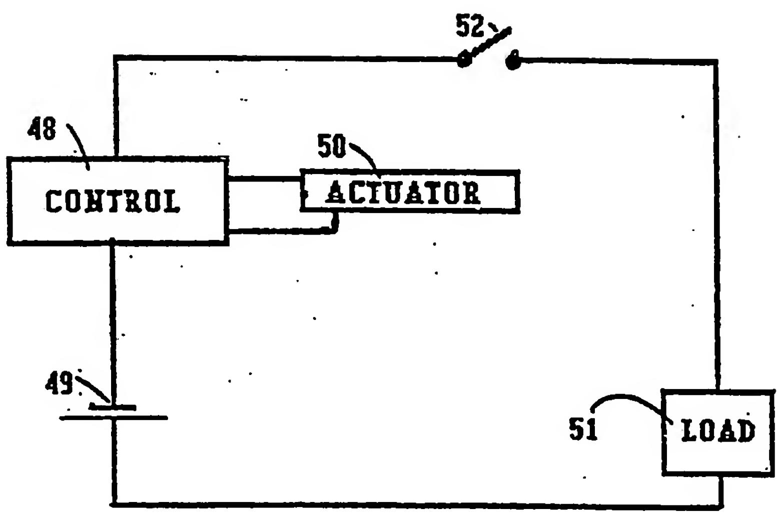

Figure 6.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/04858

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :HOLM 8/10
US CL :US 429/27,33
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : US 429/27,33

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,011,366 (Bones et al) 08 March 1977 (see claim 1, col. 3, lines 60-65).	1-34
Y	US, A, 5,069,419 (Jerman) 03 December 1991, see col. 2.	1-34
Y	US, A, 4,524,673 (Zupanic) 16 July 1985, see col. 3.	1-34
Y	US, A, 4,547,438 (Mac Arthur) 15 October 1985, see col. 2.	35-45

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 02 JULY 1993	Date of mailing of the international search report AUG 20 1993
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. NOT APPLICABLE	Authorized officer PRINCE WILLIS Telephone No. (703) 308-0661